

National Water Summary on Wetland Resources*United States Geological Survey Water Supply Paper 2425*

Technical Aspects of Wetlands

Wetland Hydrology, Water Quality, and Associated Functions

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The formation, persistence, size, and function of wetlands are controlled by hydrologic processes. Distribution and differences in wetland type, vegetative composition, and soil type are caused primarily by geology, topography, and climate. Differences also are the product of the movement of water through or within the wetland, water quality, and the degree of natural or human-induced disturbance. In turn, the wetland soils and vegetation alter water velocities, flow paths, and chemistry. The hydrologic and water-quality functions of wetlands, that is, the roles wetlands play in changing the quantity or quality of water moving through them, are related to the wetland's physical setting.

Wetlands are distributed unevenly throughout the United States because of differences in geology, climate, and source of water ([fig. 17](#)). They



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Figure 17. Major wetland areas in the United States and location of sites mentioned in the text. (Source: Data from T.E. Dahl, *U.S. Fish and Wildlife Service, unpub. data, 1991.*)

Wetlands occur on flood plains--for example, the broad bottom-land hardwood forests and river swamps (forested wetlands) of southern rivers and many of the narrow riparian zones along streams in the Western United States. Wetlands are commonly associated with lakes or can occur as isolated features of the landscape.

occur in widely diverse settings ranging from coastal margins, where tides and river discharge are the primary sources of water, to high mountain valleys where rain and snowmelt are the primary sources of water. Marine wetlands (those beaches and rocky shores that fringe the open ocean) are found in all coastal States. Estuarine wetlands (where tidal saltwater and inland freshwater meet and mix) are most plentiful in Alaska and along the southeastern Atlantic coast and the gulf coast. Alaska has the largest acreage of estuarine wetlands in the United States, followed by Florida and Louisiana.

Inland (nontidal) wetlands are found in all States. Some States, such as West Virginia, have few large wetlands, but contain many small wetlands associated with streams. Other States, such as Nebraska, the Dakotas, and Texas, contain many small isolated wetlands--the lakes of the Nebraska Sandhills, the prairie potholes, and the playa lakes, respectively. Northern States such as Minnesota and Maine contain numerous wetlands with organic soils (peatlands), similar in origin and hydrologic and vegetative characteristics to the classic bog and fen peatlands of northern Europe. However, peatlands are by no means limited to Northern States--they occur in the Southeastern and Midwestern United States wherever the hydrology and chemical environment are conducive to the accumulation of organic material.

They can form large complexes of open water and vegetation such as The Everglades of Florida, the Okefenokee Swamp of Georgia and Florida, the Copper River Delta of Alaska, and the Glacial Lake Agassiz peatland of Minnesota.

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Typical prairie pothole wetland in North Dakota. (Photograph by Virginia Carter, U.S. Geological Survey.)

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Glacial Lake Agassiz peatland, Minnesota. (Photograph by Virginia Carter, U.S. Geological Survey.)

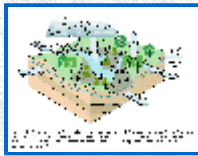
HYDROLOGIC PROCESSES IN WETLANDS

Hydrologic processes occurring in wetlands are the same processes that occur outside of wetlands and collectively are referred to as the

The relative importance of each of the components of the hydrologic cycle differs from wetland to wetland (fig. 19). Isolated basin

hydrologic cycle. Major components of the hydrologic cycle are precipitation, surface-water flow, ground-water flow, and evapotranspiration (ET). Wetlands and uplands continually receive or lose water through exchange with the atmosphere, streams, and ground water. Both a favorable geologic setting and an adequate and persistent supply of water are necessary for the existence of wetlands.

The wetland water budget is the total of inflows and outflows of water from a wetland. The components of a budget are shown in the equation in figures 18 and 19. The relative importance of each component in maintaining wetlands varies both spatially and temporally, but all these components interact to create the hydrology of an individual wetland.



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Figure 18. Components of the wetland water budget. ($P + SWI + GWI = ET + SWO + GWO + \Delta ES$, where P is precipitation, SWI is surface-water inflow, SWO is surface-water outflow, GWI is ground-water inflow, GWO is ground-water outflow, ET is evapotranspiration, and ΔES is change in storage.)

wetlands, typified by prairie potholes and playa lakes, receive direct precipitation and some runoff from surrounding uplands, and sometimes receive ground-water inflow. They lose water to ET; some lose water that seeps to ground water, and some overflow during periods of excessive precipitation and runoff. These wetlands range from very wet to dry depending on seasonal and long-term climatic cycles. Wetlands on lake or river flood plains also receive direct precipitation and runoff and commonly receive ground-water inflow. In addition, they can be flooded when lakes or rivers are high. Water drains back to the lake or river as floodwaters recede. Wet and dry cycles in these wetlands commonly are closely related to lake and river water-level fluctuations. Coastal wetlands, while also receiving direct precipitation, runoff, and ground-water inflow, are strongly influenced by tidal cycles. Peatlands with raised centers may receive only direct precipitation or may be affected by ground-water inflow also. Surface-water inflows affect only the edges of these wetlands.

Determining water budgets for wetlands is imprecise because as the climate varies from year to year so does the water balance. The accuracy of individual components depends on how well they can be measured and the magnitude of the associated errors (Winter, 1981; Carter, 1986). However, water budgets, in conjunction with information on the local geology, provide a basis for understanding the hydrologic processes and water chemistry of a wetland, understanding its functions, and predicting the effects of natural or human-induced hydrologic alterations. Each of the components is discussed below.

Water budgets provide a basis for understanding hydrologic processes of a wetland.

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Figure 19. Water budgets for selected wetlands in the United States and Canada. ($P + SWI + GWI = ET + SWO + GWO + \Delta ES$, where P is precipitation, SWI is surface-water inflow, SWO is surface-water outflow, GWI is ground-water inflow, GWO is ground-water outflow, ET is evapotranspiration, and ΔES is change in storage. Components are expressed in percentages. Abbreviations used: < = less than; > = greater than.) (Sources from left to right and top to bottom: Novitzki, 1978; Roulet and Woo, 1986; Rykiel, 1984; Rykiel, 1984; Mitsch and Gosselink, 1993; and Gehrels and Mulamootil, 1990.)

Precipitation

Precipitation is any form of water, such as rain, snow, sleet, hail, or mist, that falls from the atmosphere and reaches the ground.

Precipitation provides water for wetlands directly and indirectly. Water is provided for a wetland directly when precipitation falls on the wetland or indirectly when precipitation falls outside the wetland and is transported to the wetland by surface- or ground-water flow. For example, snow that falls on wetland basins provides surface-water flow to wetlands during spring snowmelt. Snowmelt may also recharge ground water, sustaining ground-water discharge to wetlands during summer, fall, and winter.

The distribution of precipitation across the United States is affected by major climatic patterns. In North America, maximum rainfall is found on the western slopes of mountain ranges in the West, along the east coast, and in Hawaii. Tropical areas such as Florida and Puerto Rico also receive large quantities of precipitation. By contrast, precipitation is minimal in the continental interior where the atmosphere is dry; the driest part of North America is the southwestern desert. Wetlands are most abundant in areas with ample precipitation.

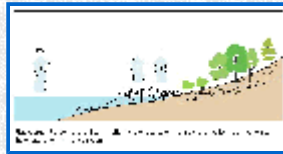
Evapotranspiration

The loss of water to the atmosphere is an important component of the wetland water budget. Water is removed by evaporation from soil or surfaces of water bodies and by transpiration by plants (fig. 20). The combined loss of water by evaporation and transpiration is termed evapotranspiration (ET). Solar radiation, windspeed and turbulence, relative humidity,

Evapotranspiration is highly variable both seasonally and daily (Dolan and others, 1984). ET losses from wetlands vary with plant species, plant density, and plant status (whether the plants are actively growing or are dormant). Seasonal changes in ET also relate to the water-table position (Ingram, 1983) (more water evaporates from the soil or is transpired by plants when the

available soil moisture, and vegetation type and density affect the rate of ET. Evaporation can be measured fairly easily, but ET measurements, which require measuring how much water is being transpired by plants on a daily, weekly, seasonal, or yearly basis, are much more difficult to make. For this reason scientists use a variety of formulas to estimate ET and there is some controversy regarding the best formula and the accuracy of these estimates (Gehrels and Mulamootil, 1990; Carter, 1986; Dolan and others, 1984; Idso, 1981).

water table is closer to land surface) and also to temperature changes (more water evaporates or is transpired in hot weather than in cold). Daily ET rates are controlled chiefly by the energy available to evaporate water--there is generally less at night and on cool, cloudy days.



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Figure 20. Percentage of transpiration and evaporation from various wetland components. (E, evaporation; T, transpiration.)

Surface Water

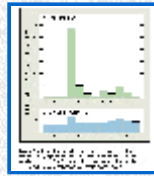
Surface water may be permanently, seasonally, or temporarily present in a wetland. Surface water is supplied to wetlands through normal streamflow, flooding from lakes and rivers, overland flow, ground-water discharge, and tides. Ground water discharged into wetlands also becomes surface water. Surface-water outflow from wetlands is greatest during the wet season and especially during flooding. Surface water may flow in channels or across the surface of a wetland. Flow paths and velocity of water over the surface of a wetland are affected by the

In coastal areas, tides provide a regular and predictable source of surface water for wetlands, affecting erosion, deposition, and water chemistry. The magnitude of daily high and low tides is affected by the relative position of the sun and the moon--highest and lowest tides usually occur during full or new moons. Where tidal circulation is impeded by barrier islands (for example, in the Albemarle-Pamlico Sound in North Carolina, where tides are primarily wind-driven) or dikes and levees, tidal circulation may be small or highly modified. Strong winds and

topography and vegetation within the wetland.

storms can cause extreme changes in sea level, flooding both wetlands and uplands.

Streamflow from wetlands that have a large component of ground-water discharge tends to be more evenly distributed throughout the year than streamflow from wetlands fed primarily by precipitation (fig. 21). This is because ground-water discharge tends to be relatively constant in quantity compared with precipitation and snowmelt.



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Figure 21. Monthly streamflow from two wetlands in northern Minnesota; A, a perched bog whose inflow component is primarily precipitation, and B, a fen whose inflow component is primarily ground water. (Source: Modified from Boelter and Verry, 1977.)

Ground Water

Ground water originates as precipitation or as seepage from surface-water bodies.

Precipitation moves slowly downward through unsaturated soils and rocks until it reaches the saturated zone. Water also seeps from lakes, rivers, and wetlands into the saturated zone. This process is known as ground-water recharge and the top of the saturated zone is known as the water table. Ground water in the saturated zone flows through aquifers or aquifer systems composed of permeable rocks or other earth materials in response to hydraulic heads (pressure). Ground water can flow in shallow

The accumulation and composition of peat in wetlands are important factors influencing hydrology and vegetation. It was long assumed that the discharge of ground water through thick layers of well-decomposed peat was negligible because of its low permeability, but recent studies have shown that these layers can transmit ground water more rapidly than previously thought (Chason and Siegel, 1986). Peatland type (fen or bog) and plant communities are affected by the chemistry of water in the surface layers of the wetland; the source of water (precipitation, surface water, or ground water)

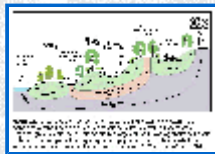
local aquifer systems where water is near the land surface or in deeper intermediate and regional aquifer systems (fig. 22). Differences in hydraulic head cause ground water to move back to the land surface or into surface-water bodies; this process is called ground-water discharge. In wetlands that are common discharge areas for different flow systems, waters from different sources can mix. Ground-water discharge occurs through wells, seepage or springs, and directly through ET where the water table is near the land surface or plant roots reach the water table. Ground-water discharge will influence the water chemistry of the receiving wetland whereas ground-water recharge will influence the chemistry of water in the adjacent aquifer.

Wetlands most commonly are ground-water discharge areas; however, ground-water recharge also occurs. Ground-water recharge or discharge in wetlands is affected by topographic position, hydrogeology, sediment and soil characteristics, season, ET, and climate and might not occur uniformly throughout a wetland. Recharge rates in wetlands can be much slower than those in adjacent uplands if the upland soils are more permeable than the slightly permeable clays or peat that usually underlie wetlands.

controls the water chemistry and determines what nutrients are available for plant growth. Ground-water flow in extensive peatlands such as the Glacial Lake Agassiz peatland in Minnesota may be controlled by the development of ground-water mounds (elevated water tables fed by precipitation) in raised bogs where ground water moves downward through mineral soils before discharging into adjacent fens (Siegel, 1983; Siegel and Glaser, 1987). Movement of the ground water through mineral soils increases the nutrient content of the water.

Coastal wetlands and shallow embayments represent the lowest point in regional and local ground-water flow systems; ground water discharges into these areas, sometimes in quantities large enough to affect the chemistry of estuaries (Valiela and Costa, 1988; Valiela and others, 1990). The quantity of ground water discharged varies throughout the tidal cycle, affecting the water chemistry of the wetland soils (Harvey and Odum, 1990; Valiela and others, 1990).

The hydrology of a wetland is largely responsible for the vegetation of the wetland.

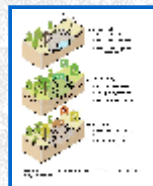


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Figure 22. Ground-water flow systems. Local ground-water flow systems are recharged at topographic highs and discharged at immediately adjacent lows. Regional ground-water flow systems are recharged at the major regional topographic highs and discharged at the major regional topographic lows. Intermediate flow systems lie between the other two

Storage

Storage in a wetland consists of surface water, soil moisture, and ground water. Storage capacity refers to the space available for water storage--the higher the water table, the less the storage capacity of a wetland. Some wetlands have continuously high water tables, but generally, the water table fluctuates seasonally in response to rainfall and ET. Storage capacity of wetlands is lowest when the water table is near or at the surface--during the dormant season when plants are not transpiring, following snowmelt, and (or) during the wet season (fig. 23). Storage capacity increases during the growing season as water tables decline and ET increases. When storage capacity is high, infiltration may occur and the wetland may be effective in retarding runoff. When water tables are high and storage capacity is low, any additional water that enters the wetland runs off the wetland rapidly.



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Figure 23. Seasonal changes in storage capacity and evapotranspiration (ET) in wetlands.

SOME EFFECTS OF HYDROLOGY ON WETLAND VEGETATION

The hydrology of a wetland is largely responsible for the vegetation of the wetland, which in turn affects the value of the wetland to animals and people. The duration and seasonality of flooding and (or) soil saturation, ground-water level, soil type, and drainage characteristics exert a strong influence on the number, type, and distribution of plants and plant communities in wetlands.

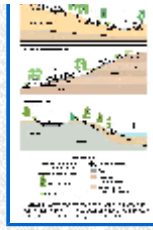
Although much is known about flooding tolerance in plants, the effect of soil saturation in the root zone is less well understood. Golet and Lowry (1987) showed that surface flooding and duration of saturation within the root zone, while not the only factors influencing plant growth, accounted for as much as 50 percent of the variation in growth of some plants. Plant distribution is also closely related to wetland water chemistry; the water may be fresh or saline, acidic or basic, depending on the source (s).

The vegetation affects the value of the wetland to animals and people.

HYDROGEOLOGIC SETTINGS

The source and movement of water are very important for assessing wetland function and predicting how changes in wetlands will affect the associated basin. Linkages between wetlands, uplands, and deepwater habitats provide a framework for protection and management of wetland resources. Water moving into wetlands has chemical and physical characteristics that reflect its source. Older ground water generally contains chemicals associated with the rocks through which it has moved; younger ground water has fewer minerals because it has had less time in contact with the rocks. Which processes can and will occur within the wetland are determined by the characteristics of the water entering and the characteristics of the wetland itself--its size, shape, soils, plants, and position in the basin.

Because wetlands occur in a variety of geologic and physiographic settings, attempts have been made to group or classify them in such a way as to identify similarities in hydrology. For example, Novitzki (1979, 1982) developed a hydrologic classification for Wisconsin wetlands based on topographic position and surface water-ground water interaction; Gosselink and Turner (1978) grouped freshwater wetlands according to hydrodynamic energy gradients; and Brinson (1993) developed a hydrogeomorphic classification for use in evaluating wetland function. (See the articles "Wetland Definitions and Classifications in the United States" and "Wetland Functions, Values, and Assessment" in this volume.) Wetlands, like lakes, are associated with features where water tends to collect. They are commonly found in topographic depressions, at slope breaks, in areas of stratigraphic change, and in permafrost areas (fig. 24) (Winter and Woo, 1990).



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Figure 24. Cross sections showing principal hydrogeologic settings for wetlands; A, slope break and depression, B, area of stratigraphic change, and C, permafrost area.

Topographic Depressions

Most wetlands occur in or originate in topographic depressions--these include lakes, wetland basins, and river valleys (fig. 24A). Depressions may be formed by movement of glaciers and water; action of wind, waves, and tides; and (or) by processes associated with tectonics, subsidence, or collapse.

Glacial movement.--Glaciers shaped the landscape of many of the Northern States and caused wetlands to form in mountainous areas such as the Rocky Mountains and the northern Appalachians. As the glaciers advanced over the Northern United States they gouged and scoured the land surface, making numerous depressions, depositing unsorted glacial materials, and burying large ice masses. As the climate warmed, the glaciers retreated, leaving behind the depressions and the large masses of buried ice. As the temperatures continued to warm, the ice masses melted to form kettle holes. In many cases, water filled the depressions and kettle holes, forming lakes. As the lakes filled with sediments, they were replaced by wetlands.

Wind, wave, and tidal action.--Wetlands are common in areas of sand dunes caused by wind, waves, or tides. Wetlands formed in the depressions between sand dunes are found in the Nebraska Sandhills, along the shoreline of the Great Lakes, and on barrier islands and the seaward margins of coastal States. In coastal States, tides, waves, and wind cause the movement of sand barriers and the closing of inlets, which often result in the formation of shallow lagoons with abundant associated emergent wetlands.

Tectonic activities.--Tectonic activity is responsible for depression wetlands such as Reelfoot Lake on the Mississippi River flood plain in Tennessee caused by the 1812 New Madrid earthquake. Earthquakes result when two parts of the Earth's crust move relative to each other, causing displacement of land. When this occurs, depressions may result along the lines of displacement or the flow paths of rivers may be changed, leaving isolated bodies of water. When a source of water coincides with these depressions, wetlands can form.

replaced by wetlands.

Water movement.--Wetlands also are formed by the movement of water as it flows from upland areas toward the coast. The flow characteristics of water are partly determined by the slope of the streambed. On steeply sloping land, water generally flows rapidly through relatively deep, well-defined channels. As the slope decreases, the water spreads out over a wider area and channels usually become shallower and less defined. Shallow channels tend to meander or move back and forth across the flood plain. The changes in flow path sometimes result in oxbow lakes and flood-plain wetlands. When the river floods, the isolated oxbow lakes begin to fill with sediment, providing an excellent place for more wetlands to form. Obstruction to the normal flow of water also can cause the water to change course and leave gouges in front of or channels around the obstruction, or can cause water to be impounded behind the obstruction. Many lakes and wetlands are formed behind dams made by humans or beavers.

These depressions, wetlands can form.

Subsidence and collapse features.--Land subsidence and collapse also can form depressions in which wetlands and lakes occur. In some areas, especially in the Southwest, pumping of ground water has caused the land above an aquifer to sink, forming depressions where water collects and wetlands develop. In karst topography (landscapes resulting from the solution of carbonate rocks such as limestone), such as is found in Florida, wetlands form in sinkholes. Collapse of volcanic craters produces calderas that fill with water and sediment and contain lakes or wetlands.

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Infrared color photograph of oxbow lakes in the drainage area of Hoholtna River near Sleetmute, Alaska. (*Photograph courtesy of National Aeronautics and Space Administration.*)

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Lotus in Reelfoot Lake, Tennessee. (Photograph by Virginia Carter, U.S. Geological Survey.)

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Coastal marsh along San Francisco Bay, California. (Photograph by Virginia Carter, U.S. Geological Survey.)

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This recently collapsed sinkhole, in central Florida, provides an ideal spot for a wetland to form. (Photograph by Terry H. Thompson, U.S. Geological Survey.)

Slope Breaks

The water table sometimes intersects the land surface in areas where the land is sloping. Where there is an upward break or change in slope, ground water moves toward the water table in the flatter landscape (fig. 24A) (Roulet, 1990; Winter and Woo, 1990). Where ground water discharges to the land surface, wetlands form on the lower parts of the slope. Constant ground-water seepage maintains soil saturation and wetland plant communities. The Great Dismal Swamp of Virginia and North Carolina is maintained by seepage of ground water at the slope break at the bottom of an ancient beach ridge that runs along the western edge (Carter and others, 1994).

Areas of Stratigraphic Change

Where stratigraphic changes occur near land surface, the layering of permeable and less-permeable rocks or soils affects the movement of ground water. When water flowing through the more permeable rock encounters the less permeable rock, it is diverted along the surface of the less permeable rock to the land surface. The continual seepage that occurs at the surface provides the necessary moisture for a wetland (fig. 24B). Fens in Iowa form on valley-wall slopes where a thin permeable horizontal layer of rock is sandwiched between two less permeable layers and continual seepage from the permeable layer causes the formation of peat (Thompson and others, 1992).

Permafrost Areas

Permafrost is defined as soil material with a temperature continuously below 32°F (Fahrenheit) for more than 1 year (Brown, 1974); both arctic and subarctic wetlands in Alaska are affected by permafrost (figs. 24C and 25). Permafrost has low permeability and infiltration rates. As a result, recharge through permafrost is extremely slow (Ford and Bedford, 1987). In areas covered by peat, organic silt, or dense vegetation, permafrost is commonly close to the surface. In areas covered by lakes, streams, and ponds, permafrost can be absent or at great depth below the surface-water body. The surface or active layer of permafrost thaws during the growing season. In areas where permafrost is continuous, there is virtually no hydraulic connection between ground water in

In discontinuous permafrost areas (fig. 25), unfrozen zones on south-facing slopes (in the northern hemisphere) and under lakes, wetlands, and large rivers provide hydraulic connections between the surface and the ground water below the permafrost zone. Ground-water discharge to wetlands from deeper aquifers can occur through the unfrozen zone (Williams and Waller, 1966; Kane and Slaughter, 1973). In discontinuous permafrost regions, whether a slope faces away from or toward the sun can determine the presence or absence of permafrost and thus influence the location and distribution of wetlands (Dingman and Koutz, 1974). Permafrost is sensitive to factors that upset the thermal equilibrium. Thermokarst features (depressions in the land surface caused by thawing and

hydraulic connection between ground water in the surface layer and ground water below the permafrost zone. The imperviousness of the frozen soil slows drainage and causes water to stand in surface depressions, forming wetlands and shallow lakes.

in the land surface caused by thawing and subsequent settling of the land) may be caused by regional climatic change or human activities. These depressions formed by local thawing of permafrost are usually filled with wetlands.



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Figure 25. Continuous, discontinuous, and sporadic permafrost areas of Alaska. (Source: Modified from Ford and Bedford, 1987.)

WATER QUALITY IN WETLANDS

The water chemistry of wetlands is primarily a result of geologic setting, water balance (relative proportions of inflow, outflow, and storage), quality of inflowing water, type of soils and vegetation, and human activity within or near the wetland. Wetlands dominated by surface-water inflow and outflow reflect the chemistry of the associated rivers or lakes. Those wetlands that receive surface-water or ground-water inflow, have limited outflow, and lose water primarily to ET have a high concentration of chemicals and contain brackish or saline (salty) water.

Examples of such wetlands are the saline playas, wetlands associated with the Great Salt Lake in Utah, and the permanent and semipermanent prairie potholes. In contrast, wetlands that receive water primarily from precipitation and lose water by way of surface-water outflows and (or) seepage to ground water tend to have lower

Plants can serve as indicators of wetland chemistry. In tidal wetlands, the distribution of salty water influences plant communities and species diversity. In freshwater wetlands, pH (a measure of acidity or alkalinity) and mineral and nutrient content influence plant abundance and species diversity.

concentrations of chemicals. Wetlands influenced strongly by ground-water discharge have water chemistries similar to ground water. In most cases, wetlands receive water from more than one source, so the resultant water chemistry is a composite chemistry of the various sources.

HYDROLOGIC AND WATER-QUALITY FUNCTIONS OF WETLANDS

Wetland hydrologic and water-quality functions are the roles that wetlands play in modifying or controlling the quantity or quality of water moving through a wetland. An understanding of wetland functions and the underlying chemical, physical, and biological processes supporting these functions facilitates the management and protection of wetlands and their associated basins.

The hydrologic and water-quality functions of wetlands are controlled by the following:

- Landscape position (elevation in the drainage basin relative to other wetlands, lakes, and streams)
- Topographic location (depressions, flood plains, slopes)
- Presence or absence of vegetation
- Type of vegetation
- Type of soil
- The relative amounts of water flowing in and water flowing out of the wetland

- Local climate
- The hydrogeologic framework
- The geochemistry of surface and ground water

Although broad generalizations regarding wetland functions can be made, effectiveness and magnitude of functions differ from wetland to wetland.

Natural functions of wetlands can be altered or impaired by human activity. Although slow incremental changes in the natural landscape can lead to small changes in wetlands, the accumulation of these small changes can permanently alter the wetland function (Brinson, 1988). Some of the major hydrologic and water-quality functions of wetlands--(1) flood storage and stormflow modification, (2) ground-water recharge and discharge, (3) alterations of precipitation and evaporation, (4) maintenance of water quality, (5) maintenance of estuarine water balance, and (6) erosion reduction--are discussed below.

The effectiveness and magnitude of a function varies from wetland to wetland.

Flood Storage and Stormflow Modification

Wetlands associated with lakes and streams store floodwaters by spreading water out over a large flat area. This temporary storage of water decreases runoff velocity, reduces flood peaks, and distributes stormflows over longer time periods, causing tributary and main channels to peak at different times. Wetlands with available storage capacity or those located in depressions with narrow outlets may store and release water over an extended period of time. In drainage basins with flat terrain that contains many depressions (for example, the prairie potholes and playa lake regions), lakes and wetlands store large volumes of snowmelt and (or) runoff. These wetlands have no natural outlets, and therefore this water is retained and does not contribute to local or regional flooding.

A strong correlation exists between the size of flood peaks and basin storage (percentage of basin area occupied by lakes and wetlands) in many drainage basins throughout the United States (Tice, 1968; Hains, 1973; Novitzki, 1979, 1989; Leibowitz and others, 1992). Novitzki (1979, 1989) found that basins with 30 percent or more areal coverage by lakes and wetlands have flood peaks that are 60 to 80 percent lower than the peaks in basins with no lake or wetland area. Wetlands can provide cost-effective flood control, and in some instances their protection has been recognized as less costly than flood-control measures such as reservoirs or dikes (Carter and others, 1979). Loss of wetlands can result in severe and costly flood damage in low-lying areas of a basin.

Not all wetlands are able to store floodwaters or modify stormflow; some, in fact, add to runoff. Downstream wetlands, such as those along the middle and lower reaches of the Mississippi River and its tributaries, are more effective at reducing downstream flooding than are headwater wetlands, largely as a result of larger storage capacities (Ogawa and Male, 1986). Runoff from wetlands is strongly influenced by season, available storage capacity, and soil permeability. Wetlands in basin headwaters are commonly sources of runoff because they are ground-water discharge areas. Wetlands in Alaska that are underlain by permafrost have little or no available storage capacity; runoff is rapid and flood peaks are often very high.

Wetlands can influence weather and climate.

Ground-Water Recharge and Discharge

Ground-water recharge and discharge are hydrologic processes that occur throughout the landscape and are not unique functions of wetlands. Recharge and discharge in wetlands are strongly influenced by local hydrogeology, topographic position, ET, wetland soils, season, and climate. Ground-water discharge provides water necessary to the survival of the wetland and also can provide water that leaves the wetland as streamflow. Most wetlands are primarily discharge areas; in these wetlands, however, small amounts of recharge can occur seasonally.

Recharge to aquifers can be especially important in areas where ground water is withdrawn for agricultural, industrial, and municipal purposes. Wetlands can provide either substantial or limited recharge to aquifers. Much of the recharge to the Ogallala aquifer in West Texas and New Mexico is from the 20,000 to 30,000 playa lakes rather than from areas between lakes, ephemeral streams, and areas of sand dunes (Wood and Osterkamp, 1984; Wood and Sanford, 1994). Recharge takes place through the bottoms of some streams, especially in karst topography and in the arid West. Some recharge also takes place when floodwater moves across the flood plain and seeps down into the water-table aquifer. Cypress domes in Florida and prairie potholes in the Dakotas also are thought to contribute to ground-water recharge (Carter and others, 1979). Ground-water recharge from a wetland can be induced when aquifer water levels have been drawn down by nearby pumping.

Most estuarine wetlands are discharge areas rather than recharge areas, primarily because they are on the low topographic end of local and regional ground-water flow systems. As the tide rises, water is temporarily stored on the surface of the wetland and in the wetland soils, where it mixes with the discharging freshwater. The water moves back into the estuary or tidal river as the tide ebbs. Precipitation falling on nontidal freshwater wetlands on barrier islands may recharge the shallow freshwater aquifer overlying the deeper salty water.

Alterations of Precipitation and Evaporation

Wetlands can influence local or regional weather and climate in several ways. Wetlands tend to moderate seasonal temperature fluctuations. During the summer, wetlands maintain lower temperatures because ET from the wetland converts latent heat and releases water vapor to the atmosphere. In the winter, the warmer water of the wetland prevents rapid cooling at night; warm breezes from the wetland surface may prevent freezing in nearby uplands. Wetlands also modify local atmospheric circulation and thus affect moisture convection, cloud formation, thunderstorms, and precipitation patterns. Therefore, when wetlands are drained or replaced by impermeable materials, significant changes in weather systems can occur.

Maintenance of Water Quality

Ground water and surface water transport sediments, nutrients, trace metals, and organic materials. Wetlands can trap, precipitate, transform, recycle, and export many of these waterborne constituents, and water leaving the wetland can differ markedly from that entering (Mitsch and Gosselink, 1993; Elder, 1987). Wetlands can maintain good quality water and improve degraded water.

Water-quality modification can affect an entire drainage basin or it may affect only an individual wetland. Water chemistry in basins that contain a large proportion of wetlands is usually different

Wetlands filter out or transform natural and anthropogenic constituents through a variety of biological and chemical processes. Wetlands act as sinks (where material is trapped and held) for some materials and sources (from which material is removed) of others. For example, wetlands are a major sink for heavy metals and for sulfur, which combines with metals to form relatively insoluble compounds. Some wetland mineral deposits (bog iron, manganese) are or have been important metal reserves in the past.

Organic carbon in the form of plant tissues and peat accumulates in wetlands creating a source

from that in basins with fewer wetlands. Basins with more wetlands tend to have water with lower specific conductance and lower concentrations of chloride, lead, inorganic nitrogen, suspended solids, and total and dissolved phosphorus than basins with fewer wetlands. Generally, wetlands are more effective at removing suspended solids, total phosphorus, and ammonia during high-flow periods and more effective at removing nitrates at low-flow periods (Johnston and others, 1990). Novitzki (1979) reported that streams in a Wisconsin basin, which contained 40 percent wetland and lake area, had sediment loads that were 90 percent lower than in a comparable basin with no wetlands. Wetlands may change water chemistry sequentially; that is, upstream wetlands may serve as the source of materials that are transformed in downstream wetlands. Estuaries and tidal rivers depend on the flow of freshwater, sediments, nutrients, and other constituents from upstream.

of water-borne dissolved and particulate organic materials. Some materials, for example nutrients, are changed from one form to another as they pass through the wetland (fig. 26). Most stored materials in wetlands are immobilized as a result of prevailing water chemistry and hydrology, but any disturbance can result in release of those materials.

The water purification functions of wetlands are dependent upon four principal components of the wetland--substrate, water, vegetation, and microbial populations (Hammer, 1992; Hemond and others, 1987).



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Figure 26. Simplified diagram of the nitrogen cycle in a wetland.

Substrates.--Wetland substrates provide a reactive surface for biogeochemical reactions and habitat for microbes. Wetland soils are the medium in which many of the wetland chemical transformations occur and the primary storage area of available chemicals for most plants.

Microbes.--The microbial community, which includes bacteria, algae, fungi, and protozoa, is responsible for most of the chemical transformations that occur in wetlands. In order to meet their metabolic needs, microbes use up and transform nutrients, minerals, and

area of available chemicals for most plants (Mitsch and Gosselink, 1993). Organic or peat soils differ from mineral soils in their biogeochemical properties, including their ability to hold water and bind or immobilize mineral constituents.

Water.--Ground and surface waters transport solid materials and gases to the microbial and plant communities, remove the by-products of chemical and biological reactions from the wetlands, and maintain the environment in which the essential biochemical processes of wetlands occur. Flooding or soil saturation causes oxygen-deficient conditions that markedly influence many biological transformations.

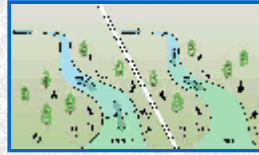
Vegetation.--Wetland vegetation reduces the flow and decreases velocities of water, causing the deposition of mineral and organic particles and constituents attached to them, such as phosphorus or trace metals. Plants introduce oxygen to the generally oxygen-deficient soil environment through their roots, creating an oxidized root zone where bacterial transformations of nitrogenous and other compounds can occur (Good and Patrick, 1987). Plants also provide a surface for microbial colonization. Wetland plants remove small quantities of nutrients, trace metals, and other compounds from the soil water and incorporate them into plant tissue, which may later be recycled in the wetland through decomposition, stored as peat, or transported from the wetland as particulate matter (Boyt and others, 1977; Tilton and Kadlec, 1979; Hammer, 1992).

oxygen, transform nutrients, manganese, and iron; and generate methane, hydrogen sulfide gas, and carbon dioxide.

Wetlands serve as short-term or long-term sediment sinks. Floodwater spreading out across a wetland decreases in velocity, and sediments settle out and are trapped within the wetland. Some of this sediment may be transported out of the wetland during future flooding. Sediment deposition in estuarine wetlands provides a constant input that is of special importance for maintenance of wetlands acreage during periods of sea-level rise (Bricker-Urso and others, 1989).

The ability of wetlands to filter and transform nutrients and other constituents has resulted in the construction and use of artificial wetlands in the United States and other countries to treat wastewater and acid mine drainage (Hammer, 1989, 1992; Wieder, 1989). However, individual wetlands have a limited capacity to absorb nutrients and differ in their ability to do so (Tiner, 1985). A wetland's effectiveness in improving water quality depends on hydrologic patterns, amount and type of vegetation, time of year, and the constituent of concern (Zedler and others, 1985).

Estuaries receive freshwater from precipitation, ground-water discharge, streamflow, and overland flow. Ground water discharges through shallow- water sediments of the estuary or through marsh soils and can affect the nutrient balance and salinity of the receiving waters (Valiela and others, 1978; Harvey and Odum, 1990). Estuarine salinity decreases during periods of high streamflow as the freshwater-saltwater interface moves down the estuary from the stream toward the sea (fig. 27). Estuarine salinity increases as streamflow decreases and the interface moves up the estuary. Estuarine plants and animals are well adjusted to these normal seasonal fluctuations in salinity. Water temporarily stored in flood-plain wetlands upstream from the estuary deposits sediment and nutrients, and water leaving these wetlands exports decomposition products and organic detritus to the estuary. This temporary storage of water and the concurrent decrease in flow velocity aid in controlling the timing and size of the freshwater influx to the estuary. For example, the freshwater wetlands of the Barataria Basin in Louisiana serve as a major freshwater reservoir for maintenance of favorable salinities in the brackish zone, and the major pulse of materials to the estuary coincides with the arrival of migrant fish for growth and spawning. Leaves that fall in flood-plain wetlands are broken down and enriched by microbial action and produce high-quality food for detrital based food chains in the estuary. Alterations in the timing and quality of streamflow and associated suspended particulate and dissolved material, caused by dams or artificial drainage, can alter the chemistry of coastal waters and affect the organisms that inhabit them.



(Click on image for a larger version, K)

Figure 27. Movement of the freshwater-saltwater interface in an estuary during periods of high flow and during periods of low flow.

Wetlands reduce the erosive forces of wind and waves.

Erosion Reduction

Wetlands reduce shoreline erosion by stabilizing sediments and absorbing and dissipating wave energy (Hammer, 1992). The ability of wetlands to stabilize and protect shorelines depends on their capacity to reduce the erosive forces of wind and waves. Beaches and shallow vegetated wetlands protect shorelines in moderate and small storms if the water does not carry excessive amounts of abrasive floating debris. Wetland vegetation decreases water velocities through friction and causes sedimentation in shallow water areas and flood-plain wetlands, thus decreasing the erosive power of the water and building up natural levees. Trees are excellent riverbank stabilizers and have been planted to reduce erosion along United States shorelines. Other wetland plants such as bulrushes, reeds, cattails, cordgrass, and mangroves can also successfully withstand wave and current action.

When vegetation is removed, streambanks collapse and channels widen and (or) deepen; removal of wetland vegetation can turn a sediment sink into a sediment source. The dissipation of erosive forces by vegetation differs from wetland to wetland and depends upon vegetative composition and root structure, sediment type, and the frequency and intensity of water contact with the bank.

SUMMARY

Wetlands are complex ecosystems in which ground water and surface water interact, but because ground water cannot be directly observed, its role in the hydrology of wetlands is sometimes more difficult to understand than that of surface water. Many wetlands owe their existence not only to poor drainage at the site but also to the discharge of ground water at the site. The hydrology of a wetland determines what functions it will perform. Each wetland is unique, but those with similar hydrologic settings generally perform similar functions.

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